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THE DISTRIBUTION OF SMALL PARTICULATES WHICH ACT AS CONDENSATION AND FREEZING NUCLEI

by

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for the
Research Department

ABSTRACT. Ground observations and measurements made over the past five years have indicated an increasing concentration of small particulates in the general atmosphere throughout the United States. Many of these minute particles act as condensation and freezing nuclei in cloud development and subsequent precipitation mechanisms; others are irritating to the eyes, nose and throat. These observations have been strengthened by aerial measurements of particulates over, and adjacent to, many of our metropolitan areas. The most pronounced changes in background nuclei and other particulate matter have been noted in the southern half of California. These studies suggest the possibility of major changes in natural precipitation amounts and increases in the stability of ground fog over large areas of California.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA • SEPTEMBER 1969

NAVAL WEAPONS CENTER

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

M. R. Etheridge, Capt., USN .... Commander
Thomas S. Amlie, Ph.D. .... Technical Director

FOREWORD

This report describes aerial and ground observations and measurements which indicate an increasing concentration of small particulates in the general aerosol throughout the United States. The work was done during the period 1 December 1968 through 30 April 1969.

This publication is a facsimile of the final report prepared by Atmospherics Incorporated of Fresno, Calif. It is issued as a Center technical publication to facilitate distribution to other interested agencies.

The work was accomplished by Atmospherics Incorporated, Fresno, Calif., under Naval Weapons Center Contract N60530-69-C-0468 and supported by Naval Air Systems Command AIRTASK A37-540/216/69-W3712-000.

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C O N T E N T

THE DISTRIBUTION OF SMALL PARTICULATES WHICH ACT AS CONDENSATION AND FREEZING NUCLEI

I INTRODUCTION AND BACKGROUND

The once clean air over the State of California is rapidly being converted to an atmospheric cesspool! The process can be reversible but meaningful measurements and stringent counter-measures must be accomplished at once.

For the past five years aerial and ground observations and measurements made by Atmospherics Incorporated (AI) have indicated an increasing concentration of small particulates in the general aerosol throughout the United States. Many of these particulates act as condensation and freezing nuclei in cloud development and subsequent precipitation mechanisms. Others are simply irritating to the eyes, nose and throat. In significant concentrations, some can be lethal!

These initial observations have been strengthened by aerial measurements of particulates over, and adjacent to, many of our metropolitan areas. The specific nature of these pollutants in the atmosphere, and the three dimensional distribution downwind from known sources, has not been adequately described. However, one point is abundantly clear. The concentrations are increasing at an alarming rate. In some areas the average concentration has increased by <u>two orders of magnitude</u> in the past three years!

From the viewpoint of cloud and fog modification in the Western United States, the most pronounced changes in background nuclei and other particulate matter have been noted in the southern half of California from San Francisco down through the great Central Valley and over the Los Angeles Basin. These observations of changes in nuclei population suggest the possibility of major changes in natural precipitation amounts and increases in the stability of ground fog over large areas of California. For example, background freezing nuclei effective at -10C. are now evident where supercooled cloud droplets at -25C. were once the rule. In areas closer to the ground there is evidence that the mean diameter of fog droplets has been reduced from the 10-15 micron range to a stable 5-10 microns. If the background nuclei population is significantly increased either by natural processes or by unidentified man-made sources, the effects on environmental processes can be enormous.

Under Contract N60530-69-C-0468 dated 6 November 1968, Atmospherics Incorporated of Fresno, California initiated a nuclei measurement mission to determine the distribution of small particulates in the central and southern California areas. The total measurement effort included the determination of Aitken nuclei with an estimate of those acting as cloud condensation nuclei, a count of background freezing nuclei active at -26C., an approximation of lead particles in the general aerosol as a function of lead iodide active at -20C., and a series of still photographs and 16mm. color footage showing a portion of the general pollution throughout the areas of interest.

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II STATEMENT OF TASKS

The objectives within the framework of this mission were accomplished during the period 1 Decmeber 1968 and 30 April 1969. The specific goals set forth under the contract can be stated in simplest terms as follows:

1. **Measurements**:
   Utilize the Atmospherics Incorporated turbocharged Aztec "C" aircraft, equipped with appropriate measuring systems, to profile condensation and freezing nuclei in the area over the southern half of California. Include in these measurements, insofar as possible, the major sources of particulate matter, the vertical and horizontal diffusion patterns of the nuclei, and provide an estimate of their role in the inadvertent modification of clouds, ground fog, and precipitation mechanisms.

2. **Data Acquisition and Reduction**:
   Data acquisition and preliminary reduction to be accomplished by Atmospherics Incorporated. Utilize this information to plot the diffusion patterns of the nuclei and establish the role of these particulates in the inadvertent modification of clouds, ground fog and precipitation mechanisms.

3. **Photography**:
   The mission shall include photographic coverage of the study area and include particular emphasis of visible pollution where measurements are accomplished. Aerial photographs including color transparencies and 16mm color cine footage shall be a part of the basic data acquisition. Organize and index the total photographic effort for submission as a supplement to the final report.

4. Reports:

Provide a progress report to the Naval Weapons Center by 1 February 1969 and a final report not later than 1 May 1969. The final report is to include a summary of effort, test results and data forms, accomplishments and recommendations.

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III EQUIPMENT AND USE

The following equipment was utilized in the accomplishment of project goals throughout the total mission.

1. Turbocharged Aztec "C"

This light twin aircraft has an altitude capability of more than 30,000 feet msl and is equipped with complete deicing systems on wings, tail surfaces and propellers. Navigational aids include dual-omni, ADF, dual 360 channel Mark 12 Nav-Com systems, Distance Measuring Equipment (DME) and FAA transponder. Six separate air intake tubes are mounted on the nose and upper cabin section for provision of air samples to the interior mounted measuring instruments. Three exhaust tubes are also available inside the cabin and provide a flushing capability for the nuclei counters and interior contamination from engine exhaust particles.

2. Portable Freezing Nuclei Detectors:

The modified portable cold boxes were used to identify freezing nuclei concentrations in the range from about one per liter up to approximately 10^5 per liter. The units contain an isothermal chamber within which an air sample may be viewed and resultant ice crystals visually counted. The sensitivity range of each unit is suitable for missions of this type because it includes both the normal level of natural background freezing nuclei effective at about -26C and the upper limit one experiences in extremely high concentration areas. Controls for varying the temperature between OC and -45C provide additional capability of determining the temperature dependence of freezing nuclei encountered in flight.

A collimated light source and grid system in the optics allows a direct reading in numbers of nuclei per cubic centimeter. Iodine vapor may be introduced into one of the instruments for detection of lead or other substances which may combine with iodine to form freezing nuclei at any given temperature. Silver vapor may be introduced into the other instrument for detection of possible free iodine.

3. Gardner Small Particle Detector:

The standard Gardner Small Particle Detector (Rich Counter) was used to measure condensation nuclei. This instrument has a range for particulate concentrations of a few per cubic centimeter to more than 10^7 per cubic centimeter. During operation an outside air sample is introduced into the instrument, a vacuum applied, the air sample expanded in a parallel chamber, and the resultant cloud density detected by the photo tube circuitry. Readout is in particles per cubic centimeter and is a function of the number of cloud droplets formed in the expansion chamber. The degree of expansion may be altered by adjusting the vacuum prior to expansion from zero through about 28 inches of mercury. Readings which result from a variety of vacuum settings give a measure of cloud condensation nuclei numbers within the gross Aitken count.

4. General Electric Continuous Condensation Nuclei Counter:

During a portion of the total mission, a General Electric Continuous Condensation Nuclei Counter was used in the aircraft as a backup system to the normal Gardner Counter. The theory of operation of the GE counter is similar to the Gardner unit whereby an air sample is taken into the instrument, expanded and the resultant cloud density detected by a photo tube electronic circuit. It is not currently known which instrument gives the most accurate and exact measurement of particulate matter concentrations, but the GE instrument with its continuous recorder is better able to describe the overall distribution of pollutants throughout the total aircraft flight path.

5. Photographic Equipment:

Cameras used during this project were the $2\frac{1}{4}$x$2\frac{1}{4}$ Rolleiflex unit, and the 16mm Kodak K-100 system. Both black and white stills and color transparencies were provided in the $2\frac{1}{4}$x$2\frac{1}{4}$ format. The 16mm coverage was provided on standard Ektachrome Commercial film. Still photographs and 16mm footage were obtained at locations thought to provide visual evidence of the normal particulate matter concentrations throughout the total operational area.

6. Millipore Filter Systems:

A standard in-line Millipore Filter Holder was installed in one of the air intake tubes during four of the measurement flights. These filters have been submitted to the Naval Weapons Center for analysis as one of the supplements to the final report.

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IV SUMMARY OF WORK PERFORMED

The primary objective of this nuclei measurement mission was to determine the gross distribution of particulate matter over that portion of California between San Francisco and the Los Angeles Basin. Toward this end, a total of 13 flights were logged and measurements were conducted at 140 sample points. The flight information and general data forms have been submitted to the Naval Weapons Center as Supplements A and B to this report.

At each of the 140 sample points several air samples were introduced into the various instruments. Subsequent measurements included a background count of freezing nuclei (Cold Box #1 -26C.) and the freezing nuclei concentration with iodine contamination in the air sample (Cold Box #2 -20C.). On one occasion silver vapor was introduced into Cold Box #1 and a check was made for presence of free iodine. While it is felt there is little or no free iodine in the atmosphere except for short distances downwind from initial sources, such as the sea surface or some unique industrial plant, there seems to be reasonable evidence that a small portion of the iodine attached to some other element or compound can recombine with silver or lead vapor to form effective freezing nuclei at specific temperature thresholds.

In addition to the freezing nuclei determinations, six condensation nuclei measurements were made with the Gardner Small Particle Detector at each of the 140 sample points. This set of CN measurements at each sample point included a series of vacuum settings beginning at about two inches of mercury and ending with the highest vacuum possible at the particular flight level associated with each location. The various vacuum settings and related CN counts at each sample point are shown on the operational data forms.

In response to a desire for information specifically related to the physical characteristics of ground fog, two of the measurement flights focused particular attention on the area around the Naval Air Station at Lemoore. These were conducted on 27 December 1968 and 15 January 1969. Ten sample points circle the station and a number of other measurement points were logged over adjacent areas. A map showing the locations of sample points logged on the two days mentioned above are shown in Figure 1.

Mr. Donald Duckering, pilot-meteorologist, was in charge of all aircraft operations including navigation, flight data acquisition, and temperature measurements. Mr. Thomas J. Henderson, meteorologist, obtained measurements from all nuclei devices, operated the photographic equipment, fed supplemental data to the IBM dictating machine and logged specific data from each sample point. This trained crew can now routinely obtain air samples, operate instruments and log reliable data in a time period of about three minutes at each sample point.

During this mission a total of 840 condensation nuclei measurements were logged, 282 freezing nuclei counts were obtained and 127 photographs have been filed. A map showing the locations of all sample points is given in Figure 2. Results obtained and conclusions reached following the data reduction phase of this mission are summarized in the following Section V.

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NUCLEI MEASUREMENT PROGRAM - NAVAL WEAPONS CENTER

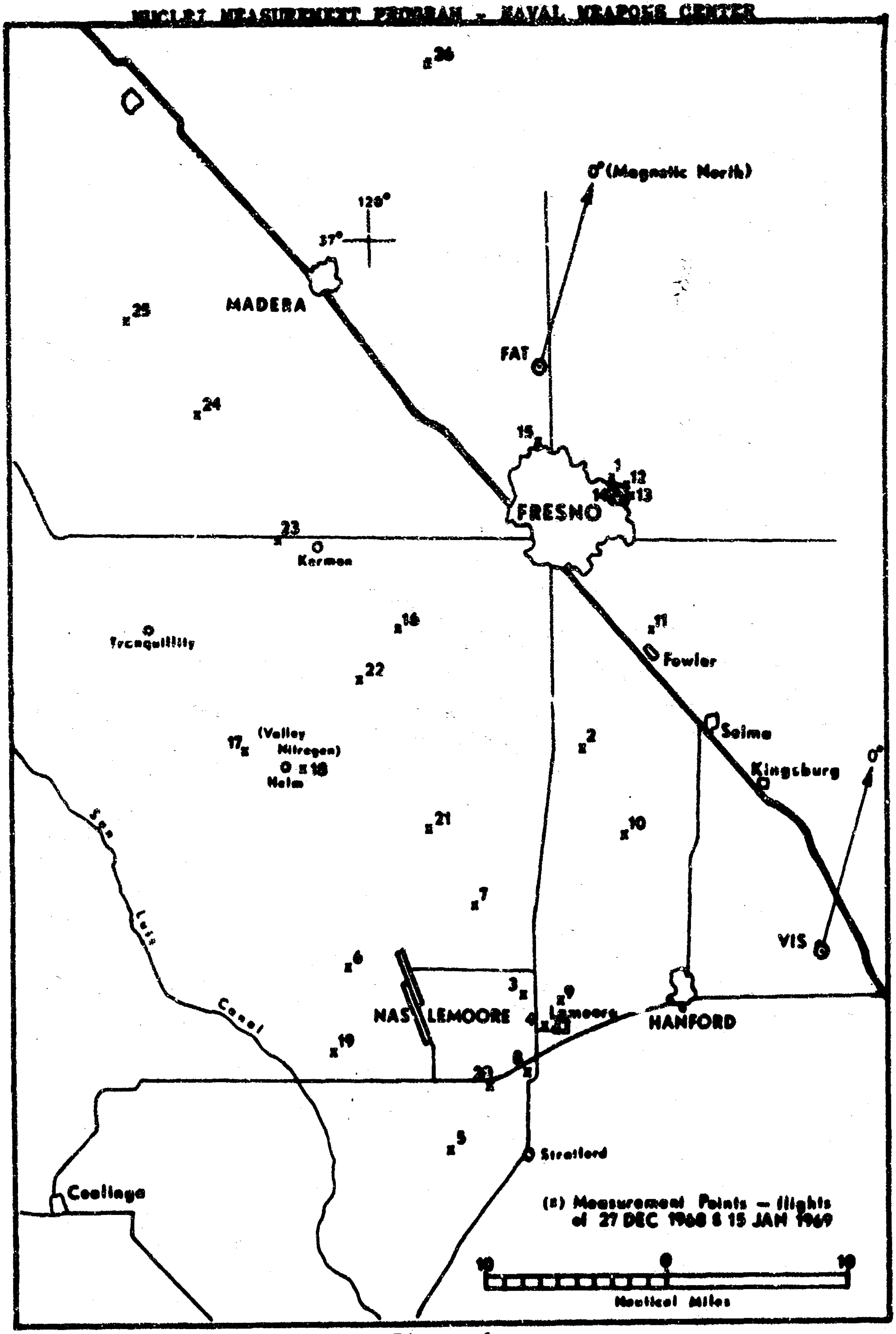


Figure 1

NUCLEI MEASUREMENT PROGRAM - NAVAL WEAPONS CENTER

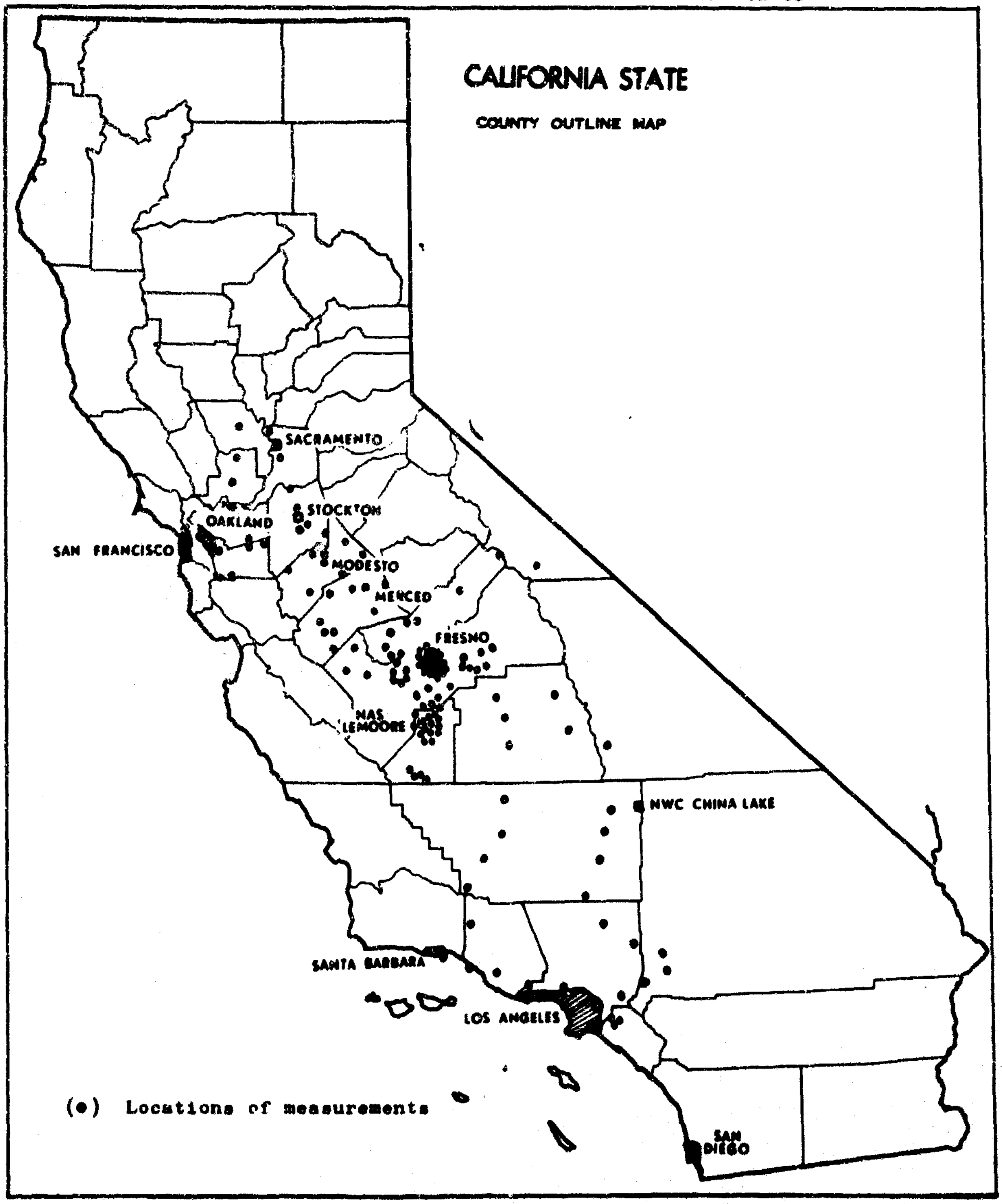


Figure 2

V RESULTS AND CONCLUSIONS:

The nuclei measurements obtained during this mission can be divided into two discrete categories -- condensation and freezing. The term "condensation nuclei" has led a number of persons to considerable confusion but, in general, the term applies to all solid and liquid particles contained in the atmospheric aerosol. This is essentially correct since all particles can act as condensation nuclei if the air is sufficiently supersaturated with water vapor. However, it should be noted that in nature the relative humidity rarely exceeds 101% so only a part of the total particulates are actually cloud condensation nuclei.

The particles can be further size categorized in terms of Aitken, large and giant nuclei. Inasmuch as this mission was not designed to identify the nuclei in great detail, the report will not provide an in-depth treatment of the physical characteristics of nuclei types and their roles in natural phenomena. It is sufficient to state that in this project the condensation nuclei measurements included the total Aitken size range which are those nuclei having radii greater than about 2.5×10^{-3} microns but less than 0.1 microns. This gives a more realistic indication of the total particulate concentrations throughout the operational area, although it does not include the small ions. More importantly, and quite beyond the role of particulates in cloud mechanisms, this measurement provides an excellent index of air pollution. Particles having radii in the range of 0.1 to 1.0 microns fall in the large nuclei category and those with radii greater than 1.0 microns are classified as giant nuclei.

For purposes of this report, freezing nuclei can be defined as those particulates which induce droplet freezing in a supercooled environment regardless of whether the process is contact nucleation, sublimation or condensation followed by freezing. Inasmuch as the air samples are first introduced into the cold chambers, cooled to -20C and -26C, and the moisture subsequently nebulized into this cold environment, most of the ice crystals which will ever form do so in about two minutes and reasonably represent the total freezing nuclei concentrations. The processes by which freezing occurs will not be described in this report.

The flight of 27 December 1968 near Lemoore NAS (Sample Points 1-12), shows the Aitken nuclei running between 1100 and 4000 cc^{-1} at altitudes between 400 and 900 feet msl. Within this total Aitken regime the cloud condensation nuclei (CCN) appear to be in concentrations of 400 to 1000 cc^{-1}. These numbers are compatible with other areas of the United States where the general terrain is flat and removed some distance from major industrial sources. However, the numbers are high for areas considered reasonably clean.

On the flight of 15 January 1969, again near Lemoore NAS, (Sample Points 13-30), the gross Aitken count was considerably higher, ranging between 1400 and 10,000 cc^{-1} at altitudes to 4000 feet msl. Of particular interest is the apparent banded structure of particulates above the land surface. Note Sample Points 21-23 where the Aitken count is higher at 3000 feet msl than at either 2000 or 4000 feet msl.

Background freezing nuclei effective at -26C and freezing nuclei with iodine contamination effective at -20C were measured on both the December and January flights. In general, all freezing nuclei counts were much higher during the 15 January flight than on 27 December. The FN concentrations were near 100 cc^{-1} (-26C) and 500 cc^{-1} (-20C iodine) during the December flight as compared with 5000 cc^{-1} (-26C) and 7000 cc^{-1} (-20C iodine) during the January flight. This is consistent with the increased level of condensation nuclei measured at the same times.

However, this does not imply the freezing and condensation nuclei concentrations are always in a linear relationship. Data taken at other times and in other areas indicate a significant departure from any positive relationship.

There seems to be reasonable evidence that the high concentration of particulates in the area of Lemoore NAS originate in some location removed from the immediate area. With moderate southerly surface winds, the particulates may be measured and observed moving northward from the Los Angeles Basin and general area throughout southern California. In case of air flow from the north, the particulates are observed heavily concentrated along the western side of the San Joaquin Valley and originating from metropolitan areas to the north. From industry, automobiles and smaller metropolitan areas all along the way south from the Sacramento-San Francisco area there are significant additions to this general particulate concentration. Of particular importance is the effluent from individual industrial sources such as chemical plants, refineries and manufacturing firms.

Another measurement flight was made on 3 March 1969 and air samples were analyzed along the path Fresno-Oakdale-Stockton-Livermore-Oakland-Patterson-Los Banos-Fresno (Sample Points 31-56). This flight was programmed to remain near the altitude of 2000-2500 feet msl. Only along the foothills north of Fresno on the east side of the Valley did the Aitken count fall below 10^4 cc^{-1} and even in this region 6500 cc^{-1} were noted. (Sample Point 32). Some of the sample points along this flight path show nuclei counts consistent with some of the most highly polluted areas in the United States. In a portion of the area southeast of Oakland even the CCN were consistently above 1000 cc^{-1} (Sample Points 43-48).

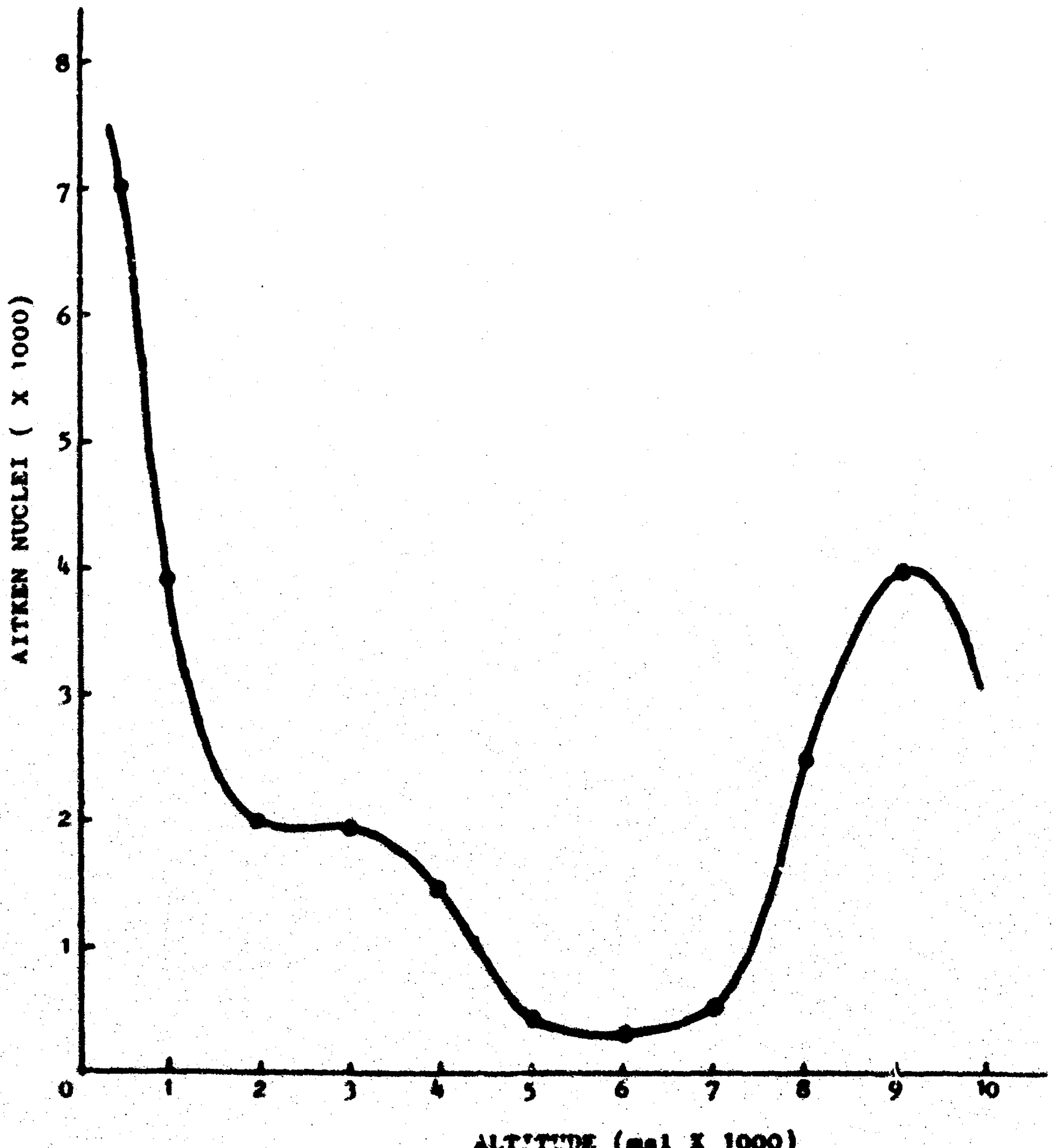
A following flight on 4 March 1969 included the route Fresno-Kaweah River-Tule River-Bakersfield-Santa Barbara-

Figure 3

AITKEN NUCLEI - vs - ALTITUDE

San Joaquin Valley - California

14 March 1969



Oxnard-Van Nuys-Los Angeles-Fullerton-Cajon Pass-Inyokern-Mt. Whitney-Fresno (Sample Points 57-94). Again we find high Aitken counts at all altitudes below 2500 feet msl and correspondingly high CCN measurements at these same elevations. Significant freezing nuclei at these same sample points were found in concentrations from 1000 to 5000 per liter at -26C.

On 5 March 1969, a second flight was made to the north of Fresno along the route Fresno-Merced-Turlock-Modesto-Stockton-Sacramento-Antioch-Tracy-Patterson-Dos Palos-Fresno (Sample Points 95-120). During this flight the heavy concentration of nuclei was particularly evident in the areas around Stockton, Sacramento, Antioch and Travis AFB. Note sample points 104 and 110-117 where the Aitken counts are all above 10^4 cc^{-1} and the CCN are in the range from 1500 to 7500 cc^{-1}. In this same area the freezing nuclei effective at -26C are also higher than on previous flights. Some are noted to be 15,000 per liter in the area of Antioch!!

The final measurement flight of this mission was logged on 14 March 1969 and included the area from Fresno south to the Tulare Lake Basin with additional measurements near Lemoore NAS. (Sample Points 121-140) A vertical profile was made to identify any possible banded structure in the aerosol. One significant layer was noted near 9000 feet msl. Note sample points 123-126 where the particulate concentration begins to increase above 6000 feet msl. The numbers associated with this particular segment of the measurement flight are graphically illustrated in Figure 3.

The data from all measurements have been analyzed and a number of conclusions are apparent.

*There is an alarming increase in particulates throughout the atmosphere from ground level to 14,000 feet msl over the southern half of California.

* The increase in particulate concentration is serious, not only from the viewpoint of atmospheric physics, but just as importantly from the viewpoints of public health, agricultural modifications, and human behavior.

* Since 1966, the concentration of Aitken nuclei over the southern portion of California has increased by more than an order of magnitude.

* This increase in particulate matter concentration may be responsible for the apparent decrease in mean droplet diameter of fog droplets in many areas of the San Joaquin Valley. Measurements made in 1965 indicated a mean diameter of 10-15 microns and this has decreased to the 5-10 micron range in 1969.

* Except during the first two flights near Fresno, California, and at those locations where automobile exhaust particulates were significant, the concentration of background freezing nuclei effective at -26C was consistently higher than freezing nuclei with iodine contamination effective at -20C.

* While the cold chamber reserved for background freezing nuclei measurements was mainly operated at -26C, there were a few occasions where the temperature was adjusted upward to -20C. In most cases the FN count was then found to be less than 10 per liter which was below the concentrations found with iodine contamination made at the same location and at the same temperature.

* While the mission was originally intended primarily as a nuclei measurement program designed to show the possible effects from particulate matter on precipitation mechanisms, the data are additionally useful as a pollution index throughout the total operational area.

* Calculations can be made which indicate the weight of solid material in the atmosphere throughout the areas where measurements were obtained.

* Diffusion patterns downwind from single or multiple sources do not follow the usual "text book" type plumes illustrated in reference volumes.

* Certain areas which are suffering high concentrations of particulate matter in the lower levels of the atmosphere may find the source of their difficulty far upwind from the local area.

* It is quite likely that an examination of pollutant material from an individual source may show a reasonably "clean" effluent but when this effluent combines, either chemically or photolytically with another nearby "clean" effluent the resultant third party may exhibit extremely detrimental characteristics.

* Most air pollution control agencies think in terms of one or two dimensions when measuring and describing particulate or gaseous material in their immediate environment. The problem cannot be adequately described in this manner. One must go to three dimensions and include a time factor before definition is significant.

All condensation and freezing nuclei measurements have been reduced and appear as a summmary in the following Table 1.

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Table 1.

NUCLEI MEASUREMENT SUMMARY

Sample Point	Height Above Sea Level (ft.)	Height Above Surface (ft.)	CN (cc^{-1})	CCN (cc^{-1})	FN background -26C. (l.$^{-1}$)	FN iodine -20C. (l.$^{-1}$)	Remarks
1	400	100	$2x10^5$	4500	5000	50000	Fresno
2	900	600	1400	300	100	500	SW Fresno
3	600	400	3100	500	100	1000	Lemoore area
4	800	600	2600	500	100	500	Lemoore area
5	900	900	1500	200	200	500	Lemoore area
6	800	600	2200	400	100	500	Lemoore area
7	800	600	3300	700	100	500	Lemoore area
8	800	600	1100	300	10	200	Lemoore area
9	500	300	4000	600	100	1000	NNE Lemoore
10	600	300	3200	500	100	1000	SW Fresno
11	900	600	3000	400	100	5000	Near Fresno
12	300	sfc.	$7x10^5$	$5x10^4$	2000	50000	Fresno runway
13	300	sfc.	$2x10^5$	7000	10000	50000	Fresno ramp
14	300	sfc.	$5x10^5$	10^4	15000	50000	Fresno ramp
15	1300	1000	10^4	1700	2000	10000	Beyond runway
16	1500	1200	7500	1200	5000	8000	Valley Nitrogen
17	1500	1300	7100	900	5000	10000	Upwind V.Nitrogen
18	800	600	7700	1200	3000	10000	Valley Nitrogen
19	800	600	8100	1600	5000	7000	Near Lemoore
20	800	600	8000	1400	5000	10000	SE Lemoore NAS
21	2000	1800	1200	200	1000	2000	NE Lemoore
22	3000	2800	3100	700	2000	2000	NE V. Nitrogen
23	4000	3800	1400	400	2000	3000	NW Fresno
24	5000	4800	1000	100	2000	4000	NW Fresno
25	6000	5800	600	50	1000	0	NW Madera
26	6000	5400	400	50	1000	0	Top of stratus
27	7300	1000	400	50	1000	0	Over foothills
28	9500	600	150	0	1000	0	Near Mammoth Mt.
29	6100	500	3100	700	2000	500	10 N. Bishop
30	4300	sfc.	7500	1100	2000	500	On final--Bishop
31	300	sfc.	$5x10^5$	5000	1000	20000	Fresno ramp
32	1700	1400	6500	900	100	500	N. of Fresno
33	400	100	$6x10^5$	9000	1000	15000	On final--Fresno
34	500	200	$4x10^4$	4200	100	1000	After takeoff
35	2000	1600	3300	700	1000	20	Fresno River
36	2000	1600	3100	500	2000	100	Along foothills
37	2000	1700	4200	900	2000	50	Over Merced R.
38	2000	1800	7600	1100	5000	500	5 S. Oakdale
39	2000	1800	9600	1200	3000	500	3 N. Oakdale
40	2500	2400	9000	1200	2000	200	5 SW Stockton

Table 1. Con't.

NUCLEI MEASUREMENT SUMMARY

Sample Point	Height Above Sea Level (ft.)	Height Above Surface (ft.)	CN (cc^{-1})	CCN (cc^{-1})	FN background -26C. (l.$^{-1}$)	FN iodine -26C. (l.$^{-1}$)	Remarks
41	2500	2300	$3x10^4$	2900	2000	1000	2 N. Tracy
42	2500	2000	10^4	1000	3000	1000	5 NW Livermore
43	2500	1800	$2.5x10^4$	3000	4000	2000	Foothills-S.Oakdale
44	2500	2000	$2.8x10^4$	3000	5000	2000	Foothills-Highway
45	2500	1700	$2x10^4$	2300	3000	1000	Turning south
46	2000	1800	$1.9x10^4$	2400	2000	500	Over canal
47	2000	1800	$1.3x10^4$	2000	2000	500	5 SW Patterson
48	2000	1700	10^4	2000	3000	1000	Over US #5
49	2000	1600	10^4	1900	2000	333	W. of Los Banos
50	2000	1800	$1.3x10^4$	2200	4000	1000	S. of Los Banos
51	2000	1800	$1.5x10^4$	2100	2000	1000	Turning east
52	2000	1800	$1.5x10^4$	1200	4000	333	W. of Fresno
53	2000	1800	9300	900	2000	250	Approaching FAT
54	2000	1700	7800	700	2000	200	3 S. Fresno
55	500	200	$4x10^4$	3700	4000	5000	On final--Fresno
56	300	Sfc.	10^6	10^4	5000	20000	Fresno ramp
57	300	Sfc.	$7x10^6$	5000	5000	50000	Fresno ramp
58	500	200.	$5x10^4$	2000	2000	10000	Above runway
59	2000	1500	4600	700	2000	1000	Over K.R.foothills
60	2000	1600	3000	500	3000	1000	Along foothills
61	2000	1600	5600	900	2000	1000	Kaweah River
62	2000	1600	4200	400	1000	500	Porterville
63	2000	1200	6500	900	2000	1000	N. Bakersfield VOR
64	2000	1500	$1.4x10^4$	2000	4000	2000	Oilwell area
65	2000	1200	9500	1200	2000	500	S. Bakersfield
66	4500	900	5400	700	2000	500	Over hills
67	5200	1600	5100	400	2000	500	Over hills
68	4500	4500	5200	300	1000	500	Over ocean
69	1600	1600	$2.5x10^4$	2100	3000	1000	Coast S.SBA
70	2000	1900	$2.1x10^4$	3200	4000	1000	E. Oxnard
71	2600	1100	$.2x10^4$	1600	2000	1000	Van Nuys area
72	2600	2400	$4.2x10^4$	1900	2000	1000	Hills N.LAX
73	2600	2400	$4.2x10^4$	7100	3000	2000	S.of LAX
74	100	Sfc.	10^7	$3x10^4$	5000	40000	Fullerton runway
75	100	Sfc.	10^6	9000	5000	20000	Fullerton ramp
76	500	400	$7x10^4$	7000	5000	2000	Takeoff-Fullerton
77	2500	1500	$4x10^4$	5100	4000	2000	N. Fullerton
78	2600	1600	$2.6x10^4$	4200	3000	1000	E. of Pomona
79	4600	1700	5600	1100	2000	500	Cajon Pass
80	5000	900	4200	700	2000	500	Desert NW Cajon

Table 1. (Con't.)

NUCLEI MEASUREMENT SUMMARY

Sample Point	Height Above Sea Level (ft.)	Height Above Surface (ft.)	CN (cc^{-1})	CCN (cc^{-1})	FN background -26C. ($l.^{-1}$)	FN iodine -26C. ($l.^{-1}$)	Remarks
81	5000	1500	5100	900	2000	1000	ESE Palmdale VOR
82	5000	2500	1900	500	1000	100	Desert area
83	5000	2600	1300	400	1000	100	Rosemond Lk.
84	5000	2600	1500	500	500	100	Near Calif.City
85	5500	2300	1000	300	500	20	Desert area
86	5500	3000	900	200	500	20	SW of Inyokern
87	8000	4100	600	100	4000	50	Mts. NW Inyokern
88	12500	mts.	300	100	5000	50	Monaches Meadow
89	14800	mts.	700	50	2000	50	W. Mt. Whitney
90	8300	mts.	700	100	3000	100	W. Fresno
91	3900	mts.	3100	500	3000	1000	Base of stratus
92	1500	mts.	5200	1700	2000	1000	Clovis
93	500	200	$3x10^5$	10^4	4000	10000	Fresno final
94	300	sfc.	$4x10^6$	$3x10^4$	4000	50000	Fresno ramp
95	300	sfc.	$7x10^4$	6500	3000	20000	Fresno ramp
96	300	200	$2x10^4$	5900	1000	10000	Above runway
97	2500	2200	2100	500	1000	200	Above haze layer
98	2000	1800	2000	600	2000	200	Near haze top
99	1500	1300	2100	600	1000	100	Farm areas
100	1000	900	3200	500	2000	100	NW Merced
101	2000	1900	4300	900	1000	200	Turlock
102	2000	1900	1700	500	2000	200	Modesto
103	2000	2000	1700	500	000	500	Stockton
104	2000	2000	$1.7x10^4$	2100	3000	1000	N. Stockton
105	2000	2000	1400	500	1000	100	Farm land
106	2000	2000	1200	200	1000	100	E. Sacramento
107	2000	2000	1500	300	1000	100	N. Sacramento
108	1500	1400	5000	700	3000	500	Woodland
109	1500	1500	2300	500	2000	500	Farmland
110	1500	1500	$2x10^4$	3700	3000	1000	Travis AFB
111	1500	1500	$7x10^4$	7500	10000	3000	Near Antioch
112	1500	1500	$1.4x10^4$	1900	15000	4000	S. Antioch
113	1500	1400	$1.2x10^4$	1500	10000	4000	Tracy
114	1500	1400	$2.1x10^4$	1700	8000	2000	3 E. Patterson
115	1500	1400	$3.2x10^4$	3900	10000	3000	San Joaquin R.
116	1500	1400	$1.6x10^4$	2700	7000	500	Farmland
117	1500	1400	$1.2x10^4$	2100	5000	200	E. Dos Palos
118	1500	1400	4900	900	1000	100	Farmland
119	1500	1300	10^4	2000	2000	200	Near Fresno
120	300	Sfc.	10^6	10^4	5000	50000	Fresno ramp

Table 1.(Con't.)

NUCLEI MEASUREMENT SUMMARY

Sample Point	Height Above Sea Level (ft.)	Height Above Surface (ft.)	CN (cc^{-1})	CCN (cc^{-1})	FN background -26C. ($l.^{-1}$)	FN iodine -26C. ($l.^{-1}$)	Remarks
121	300	Sfc.	$4x10^5$	10^4	2000	20000	Fresno ramp
122	500	200	7000	1100	1000	10000	Above runway
123	3500	3100	1600	300	1000	5000	Over foothills
124	9000	8600	3000	700	100	50	Over valley
125	8000	7700	2500	600	100	50	Over valley
126	7000	6700	500	50	20	20	Over valley
127	6000	5800	300	50	10	10	Over valley
128	5000	4800	400	50	10	10	Over valley
129	4000	3800	1600	400	100	50	Over valley
130	3000	2800	2000	500	100	65	Over valley
131	2000	1800	2000	400	100	100	Valley nr.Swartz
132	1500	1300	1900	300	100	100	Near Tulare Lk.
133	1500	1300	3100	1000	200	500	SW end of lake
134	1500	1300	1800	700	100	100	S. side of lake
135	1500	1300	1600	600	100	100	NE end of lake
136	1000	800	3900	900	200	500	Lemoore
137	800	600	2400	500	200	500	N. of Lemoore
138	1200	900	4100	1300	200	500	Near Fresno
139	500	200	$2.8x10^3$	9000	1000	5000	Fresno final
140	300	Sfc.	10^6	10^4	3000	50000	Fresno runway

VI RECOMMENDATIONS:

The results obtained from the activities under this limited program strongly indicate the need for a mission designed to identify the particulates and more accurately define their distribution. To accomplish the various aspects of such a mission, we offer the following recommendations:

Begin, at once, a more concentrated and in-depth aerial measurement program over all of California and areas east to the Rockv Mountains. Include instrumentation for a more specific identification of the particulate matter throughout the atmospheric aerosol.

On a real time basis make the field measurement program a fully cooperative effort with personnel and facilities at the Naval Weapons Center, China Lake. This will provide tentative results on a more current basis and suggest possible changes in the field program activities on a monthly instead of annual or seasonal basis.

At ground level include measurements of the physical characteristics of warm fog. These should include droplet concentration, size distribution, liquid water content and electrical characteristics. Relate these parameters to measurements of particulate matter.

Identify, classify and name the major sources of air pollution effluent and map the diffusion patterns from specific sources.

Define the meteorology throughout measurement areas on those days when data are logged and draw "pollution-weather maps" for all operational days.

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VIII LIST OF SUPPLEMENTAL SUBMISSIONS:

Following is a list of items submitted to the Naval Weapons as supplements to this final report.

SUPPLEMENT A - FLIGHT FORMS

These forms are used by the pilot during all flights associated with the total mission. The data on each form include event number, time, position of aircraft, altitude above sea level, aircraft speed, ambient air temperature, aircraft heading, altitude above ground and general notes on weather.

SUPPLEMENT B - OPERATIONAL FORMS

These forms are used by the equipment operator during each of the measurement flights. There are three sections to each form with space for freezing nuclei, condensation nuclei and photographic data. The section on freezing nuclei shows time, altitude above sea level, location number, background freezing nuclei concentrations at -26C, freezing nuclei concentrations with iodine contamination at -20C and general area of measurements. The section on condensation nuclei shows location number, time and Aitken nuclei concentration at five different levels of water saturation (inches of mercury prior to expansion). The final section is reserved for notes on photographs obtained during each flight. Supplements A and B are submitted in a single bound folder.

SUPPLEMENT C - BLACK AND WHITE PHOTOGRAPHS

This supplement is composed of 18 selected black and white photographs and printed on 8 x 10 glossy stock. The subject material is representative of the condition of the atmosphere throughout most of the measurement flights. The photographs are captioned and mounted in a single photographic folder.

SUPPLEMENT D - COLOR TRANSPARENCIES

A total of 99 2¼x2¼ color transparencies have been mounted, filed and submitted with complete index. These transparencies were obtained during the measurement flights and clearly show the atmospheric conditions and extreme concentration of particulate matter observed throughout most of the operational areas.

SUPPLEMENT E - 16mm CINE FOOTAGE

This supplement includes 300 feet of 16mm Ektachrome Commercial cine footage obtained during portions of the measurement flights. The scenes represent the observed phenomena and illustrate the general level of pollutant material visible to the flight crew. A scene by scene index is included which can be used while viewing the total footage.

SUPPLEMENT F - MILLIPORE FILTERS

Four Millipore filters have been submitted in this supplement. These filters were introduced into one of the air sample intake lines during portions of the total mission and their analysis was to be assumed by personnel at the Naval Weapons Center. The filters are indexed by dot code -- one dot meaning filter number one, two dots meaning filter number two, etc. Data relative to each of the filters is given below.

Date	Fil. No.	Area (Loc.No.)	Vol. of air Sampled (liters)	Remarks
1/15	1	13 - 30	2300	Fresno-Lemoore-Madera-Bishop
3/4	2	57 - 94	5500	Fresno-Los Angeles-Fresno
3/5	3	95 - 120	3250	Fresno-Sac.-Tracy-Fresno
3/14	4	121 - 140	4200	Fresno-Lemoore-Fresno

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PHOTO 1. (NNM) Atmospherics Incorporated turbocharged Aztec "C" used for Nuclei Measurement Mission. Aircraft is equipped with full panel of navigational and communications equipment including Transponder and DME. Instruments for measurements of freezing and condensation nuclei are part of the interior package. Temperature profiles are obtained with Rosemount probe and Liquid Water Content is available with the normal Johnson-Williams sensor.

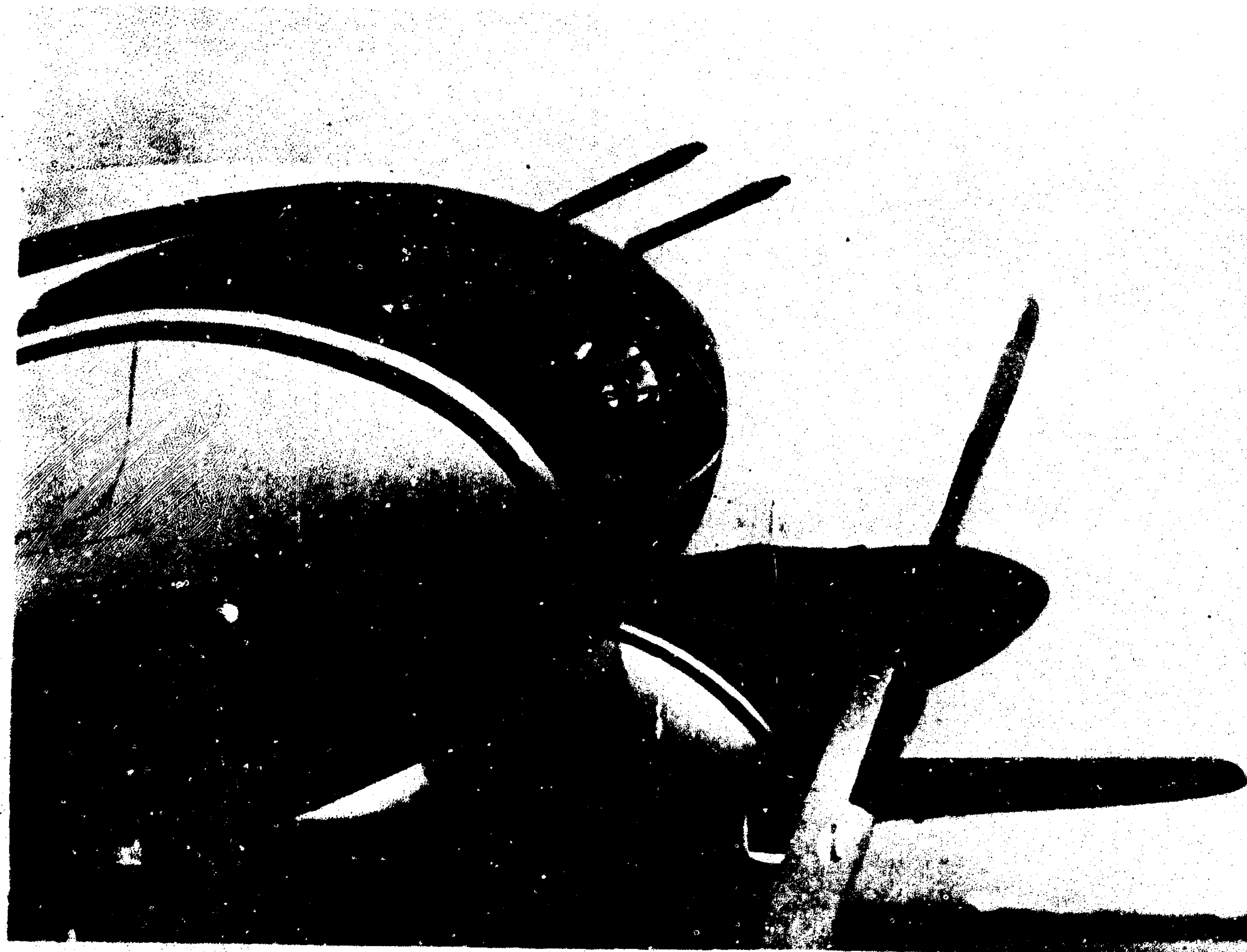

PHOTO 2. (NNM) Nose of Aztec "C" showing air sample inlet probes. Each probe contains two inlet tubes capable of providing volumes of about one liter per minute. Two high volume inlet probes on the top of the aircraft cabin provide volumes of about 20 liters per minute. All volumes are computed on the basis of aircraft speeds near 55 meters per second. Inlet tubes are connected to instruments by Tygon tubing.

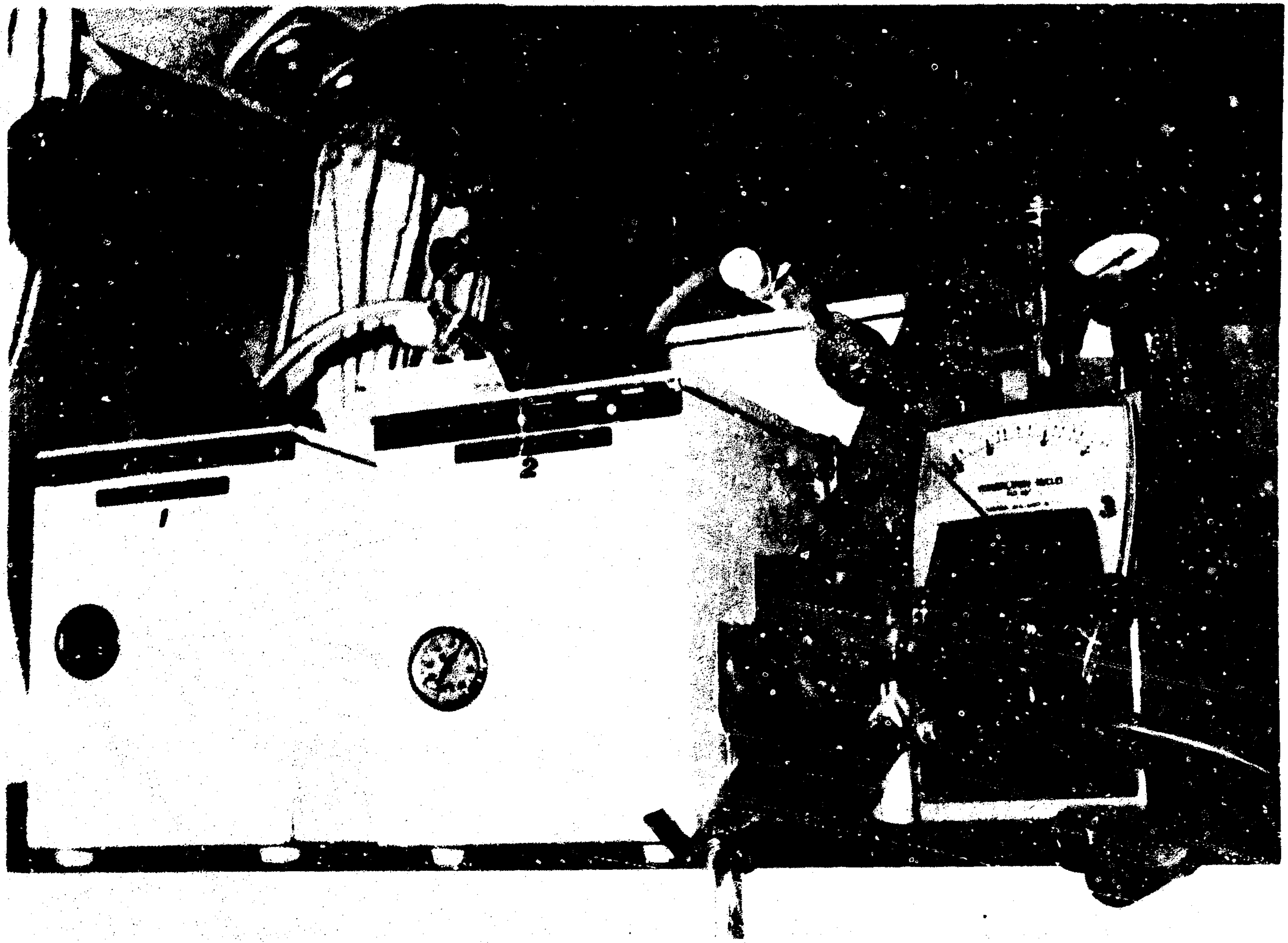

PHOTO 3. (NNM) Two freezing nuclei counters are shown on the left inside the Aztec "C" aircraft cabin. Detection limits for freezing nuclei are in the range from about 1 per liter through 100,000 per liter. Gardner Small Particle Detector is shown on the right. The range of this instrument for Aitken Nuclei is from about 50 per cubic centimeter through more than 10,000,000 per cubic centimeter.

PHOTO 4. (NNM) General pollution over the San Joaquin Valley in December 1968. View is looking SW from a point south of Fresno. Particulate matter concentration here is rather uniform throughout elevations from ground level up to 5,000 feet msl. This is not considered a heavily polluted situation by the people on the ground although the Aitken nuclei count is more than 10,000 per cc.

... Sierra from ... Top of the main pollution layer ... alley even though upper cloud deck may indicate ... and freez... ...tions remain high until mixing occurs.

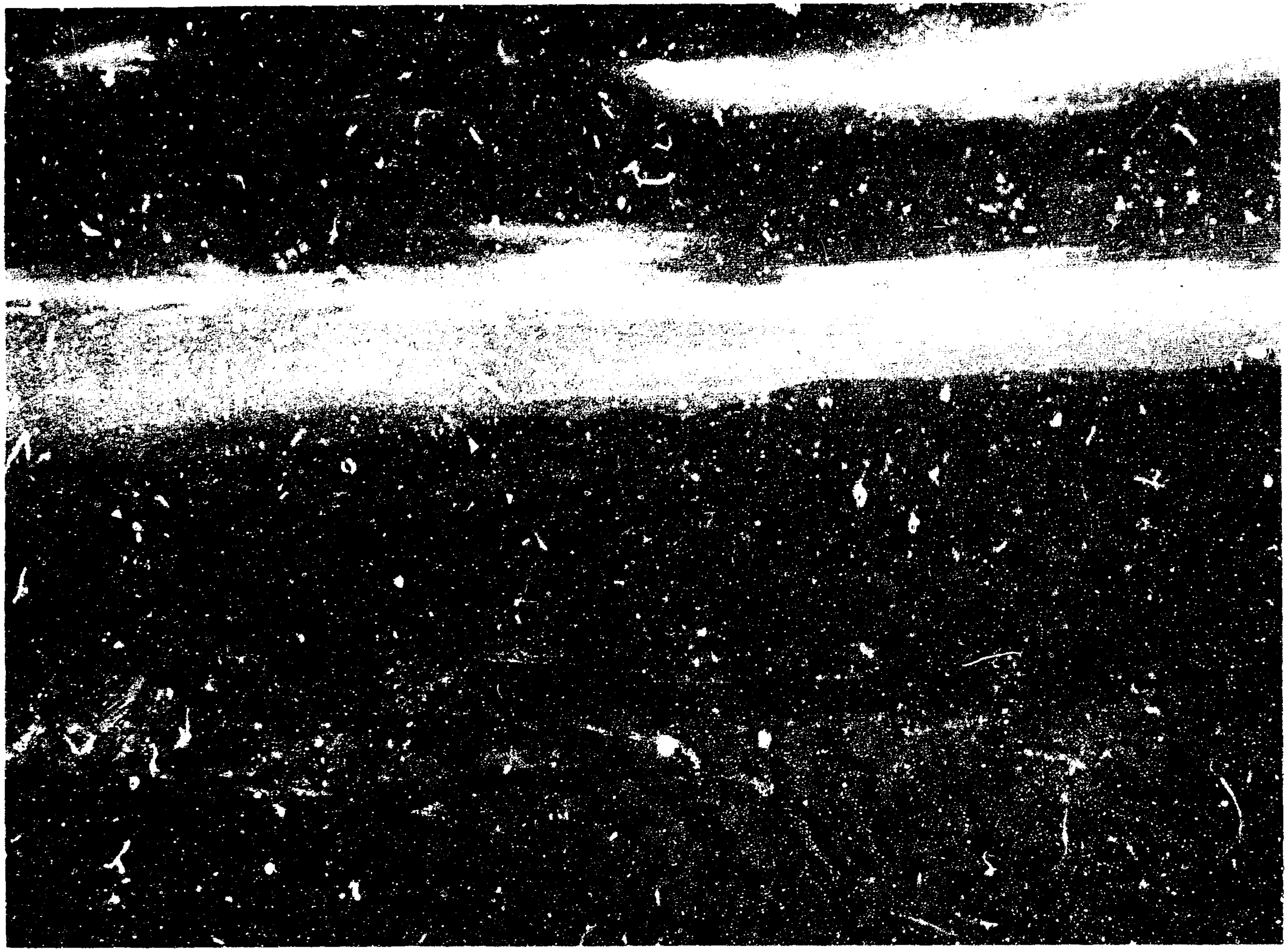

PHOTO 6. (NNM) View looking toward the Sierra across the upper portion of Pine Flat Reservoir. Note the heavy concentration of particulates at elevations up to 10 000 feet msl. Condensation nuclei "pile up" along the foothills of the Sierra and along the eastern side of the Coast Range depending upon wind directions and source of pollutants. Clean air is seldom noted in foothills.

PHOTO 7. (NNM) View looking south along the foothills of the Sierra from a point east of Fresno. This is not fog. It is an example of the concentration of particulate matter which is now a normal situation in this area as well as many other areas throughout California. Concentrations increase as one moves south.

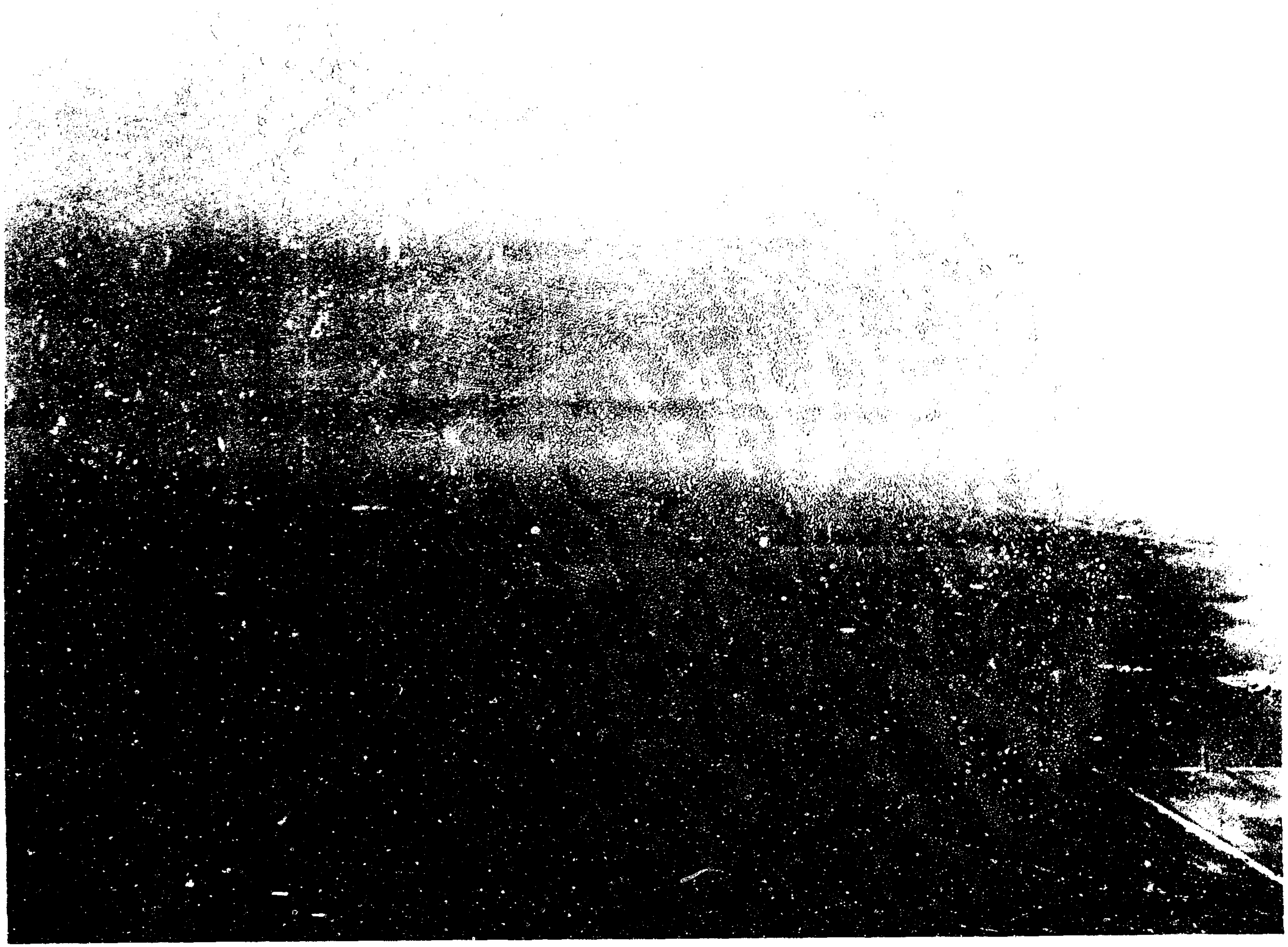

PHOTO 8. (NNM) Another view looking toward the Sierra from a point 2 miles SW of Fresno. At this flight altitude of 900 feet msl, the condensation nuclei concentration is only 3,000 per cc but further east toward the mountains the concentrations are considerably higher. It is interesting that here the freezing nuclei concentration with iodine contamination at -20C is higher than the background freezing nuclei active at -26C.

PHOTO 9. (NNM) Looking easterly from a point immediately east of the Fresno Air Terminal. Notice the banded structure of the particulate matter in the distance. This is a common phenomenon and is often seen in multiple bands at higher elevations above the land surface. Photo was taken in February 1969 following passage of a short storm period.

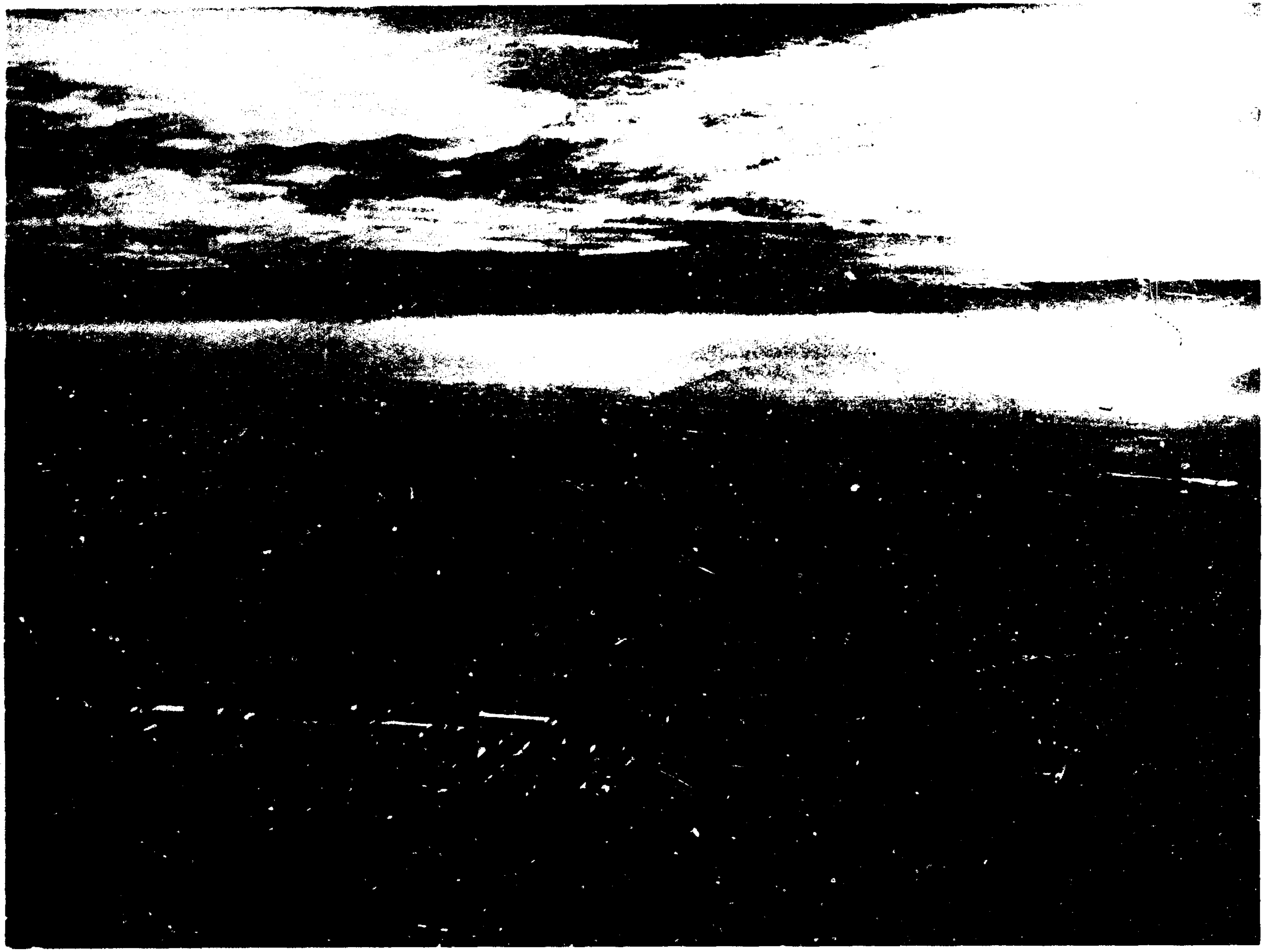

PHOTO 10. (NNM) 9 February 1969 0824. View looking easterly toward the Kings River Watershed. Note the top of the general pollution layer is intersecting the foothills at about 3,500 feet msl. The top of this layer was normally at an elevation of about 1,500 feet msl in 1966 and the concentration of particulates was an order of magnitude less in most of the high pollution areas.

PHOTO 11. (NHM) Concentration of particulate matter over the southern section of the San Joaquin in February 1969. Flight level is considerably above the main area of pollution and note how the material meanders up through the mountain canyons in the distant second and third row of mountains.

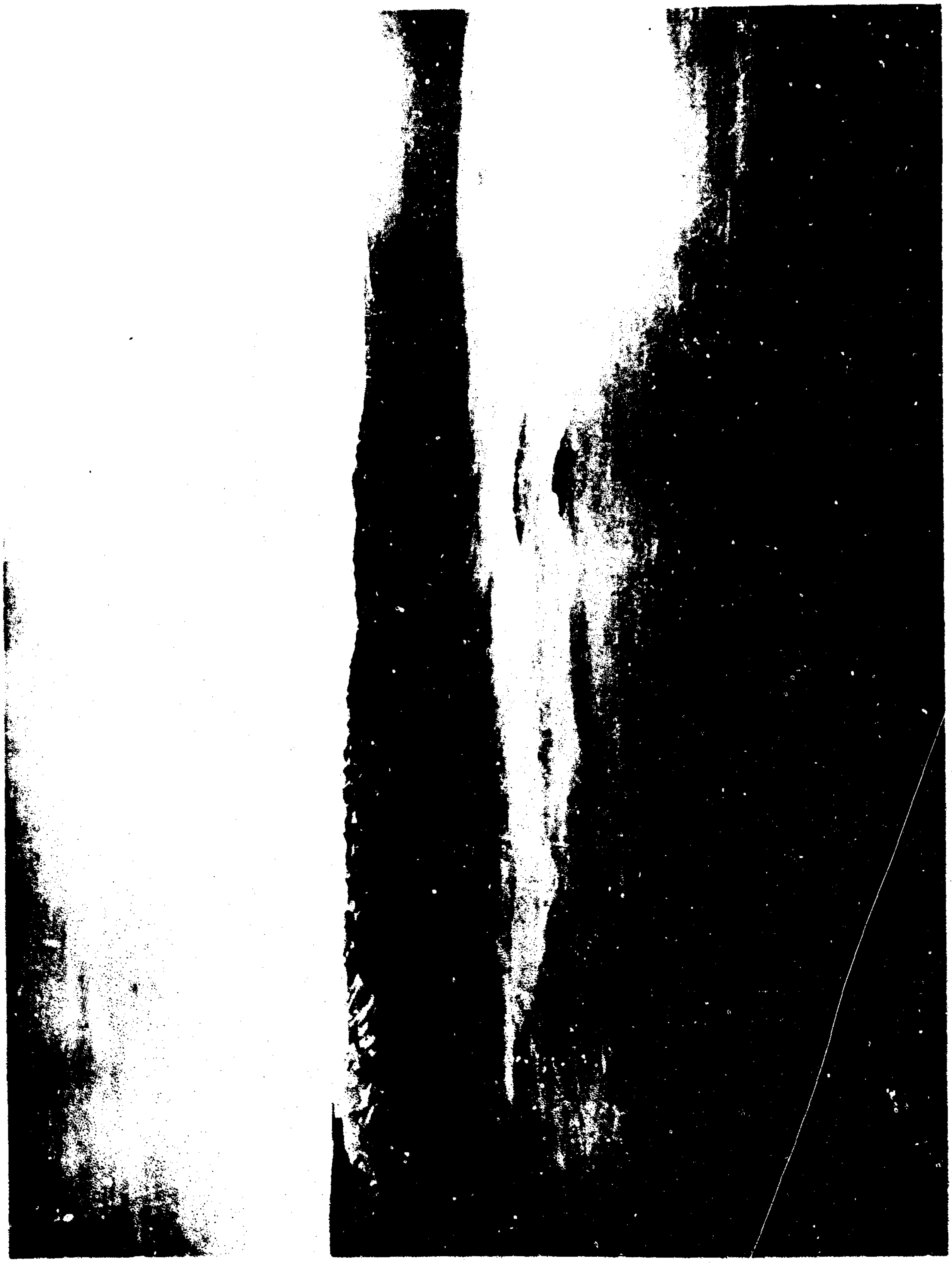

PHOTO 12. (NNW) Toward the Sierra Mountains from a point near Visalia, California. Note how the pollution concentrates in areas and does not diffuse in predictable patterns either vertically or horizontally. Increasing concentrations of material in the air are not particularly noticeable at ground level but overflights present a graphic picture of the problem.

PHOTO 13. (NNM) View looking easterly over Tehachapi Mountains toward the area south of China Lake. Notice the plume from the cement plant in center of photograph. The meandering in thin "pencil like" pattern downwind from the source is often seen from single point sources such as this cement plant stack. Plume behavior is seldom like those shown in textbooks describing such phenomena.

PHOTO 14. (NNM) 9 February 1969 0800. Los Angeles Basin looking easterly from point north of the city. The concentration of particulate matter in this area is seldom less than 10,000 per cc. The main source is local and contains much effluent from automobiles. Lead is a prime constituent and is measurable with the iodine contamination technique in one of the freezing nuclei instruments aboard the Atmospherics Incorporated Aztec "C."

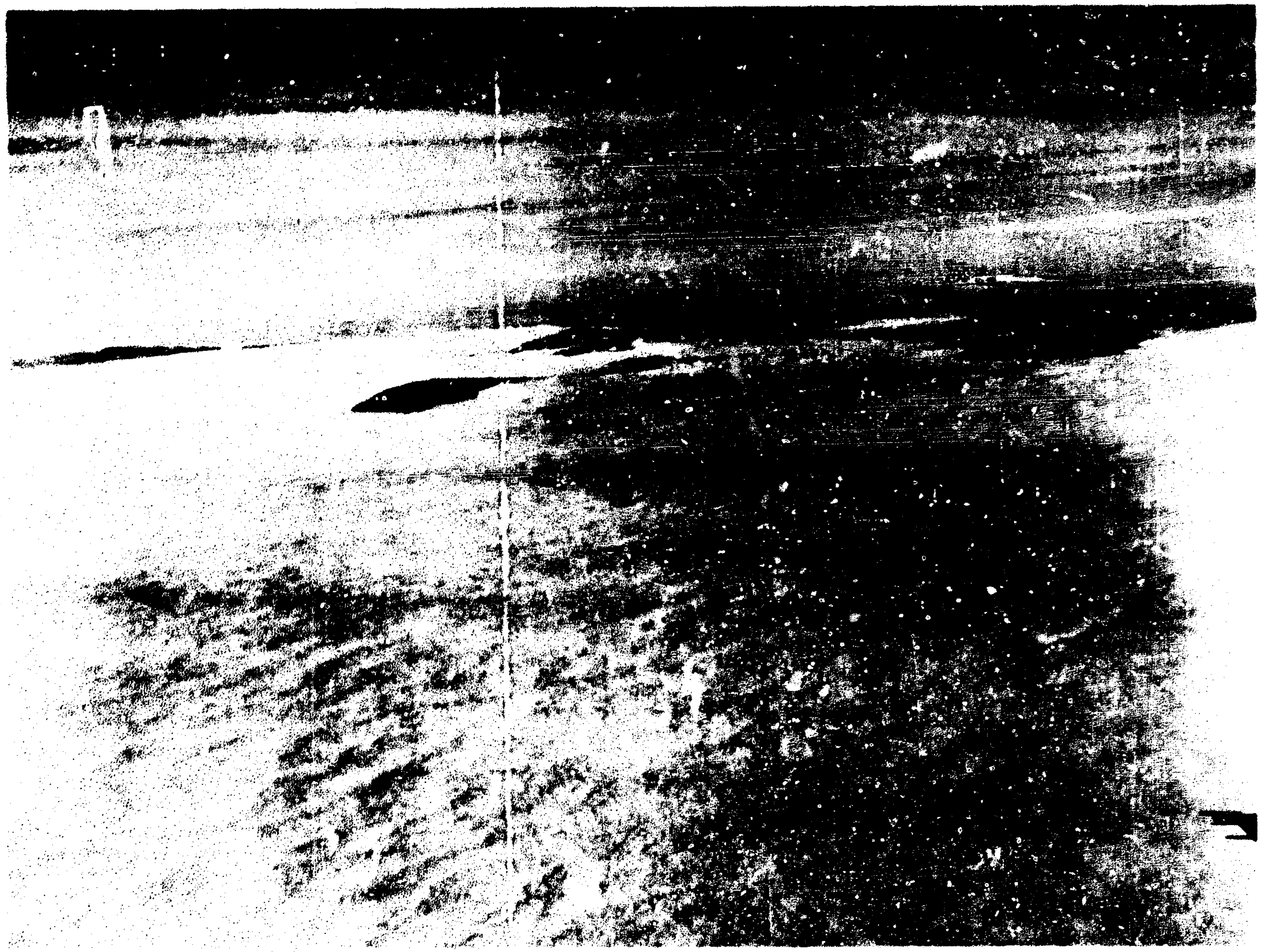

PHOTO 15. (NNM) Fog layer over southern section of San Joaquin Valley in January 1969. This stable fog is common in winter months throughout much of California and its physical characteristics are further complicated by the increasing concentration of particles in the atmosphere. View is looking easterly from a point south of Bakersfield.

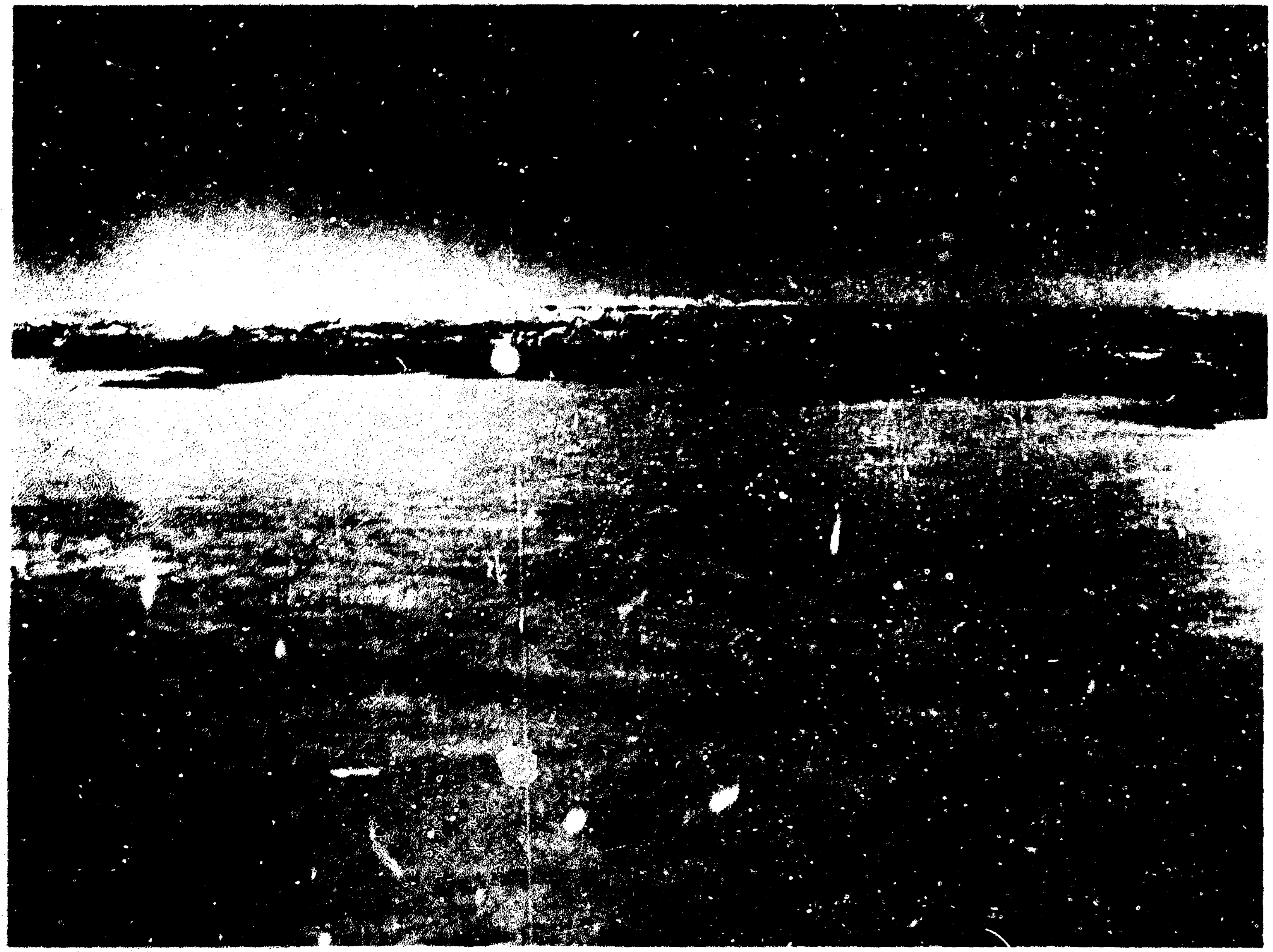

PHOTO 16. (NNM) Another view of the fog layer over the San Joaquin Valley in January 1969. View is looking NE from point south of Fresno and the Sierra Range near Kings River clearly shows in the background. The mean diameter of droplets in this fog have been reduced from 10-15 microns to 1-10 microns during the past four years. Increased concentration of particulate matter throughout the fog may be a major contributing factor.

PHOTO 17 (NN' As fog begins to dissipate, the concentration of particulates may be seen over all of the area in this

PHOTO 18. (NNM) View looking easterly from a point near Fresno, California, shows moderate pollution layer along the foothills. This is considered a very clean day and is sometimes noted following a storm period. Rate at which the pollution particles return to the total area is extremely rapid. In less than 24 hours the condensation nuclei count often returns to 10,000 per cc following major storm periods.

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Security Classification

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13. ABSTRACT

Ground observations and measurements made over the past five years have indicated an increasing concentration of small particulates in the general atmosphere throughout the United States. Many of these minute particles act as condensation and freezing nuclei in cloud development and subsequent precipitation mechanisms; others are irritating to the eyes, nose and throat. These observations have been strengthened by aerial measurements of particulates over, and adjacent to, many of our metropolitan areas. The most pronounced changes in background nuclei and other particulate matter have been noted in the southern half of California. These studies suggest the possibility of major changes in natural precipitation amounts and increases in the stability of ground fog over large areas of California.

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